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COMPOSITE WIRES
for OPERATION as ELECTRICAL CONDUCTORS
at ELEVATED TEMPERATURES

by James R. Howell
Supervisor, Wire Product Engineering
PARTS DIVISION of
SYLVANIA Electric Products Inc.
Warren, Pennsylvania

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Today, in wiring for the aircraft industry, conductor temperatures of 750° F are necessary; tomorrow, with increasing aircraft speeds, conductors operating at ambient temperatures, 1000° F and up, will be required. Interest in "ultra" high temperature wire for application in other fields will naturally follow. Sylvania's approach to this problem is through composite wires, employing either an electroplating process or a "cladding" process, depending on the thickness of coating required and the metal required to provide protection in oxidizing and corrosive atmospheres. In the plating process, wire is plated at rod size and then cold drawn to finish diameter. In the "cladding" process, a high conductivity rod is inserted into a seamless tube and the composite rod is cold drawn to the finish diameter. In either method, high electrical conductivity is provided by the "core" material while the coated metal provides protection against the various environmental conditions.

Copper, due to its high electrical conductivity, is normally selected as the core material. For applications where a lower temperature coefficient of resistivity is required (less resistance change as temperature varies over the operating range), copper-base alloys can be used; however, this is done at the sacrifice of conductivity. Electrical conductivity and temperature coefficient vary with the composition of the alloy and are substantially proportional to each other. For example, figure 1 shows the practical linear relationship that exists for the copper–nickel system up to 45% nickel in copper. This chart clearly illustrates the high loss in conductivity with small additions of nickel in order to obtain a lower temperature coefficient. Figure 2 shows percent conductivity at various temperatures for several different percentages of nickel in copper.

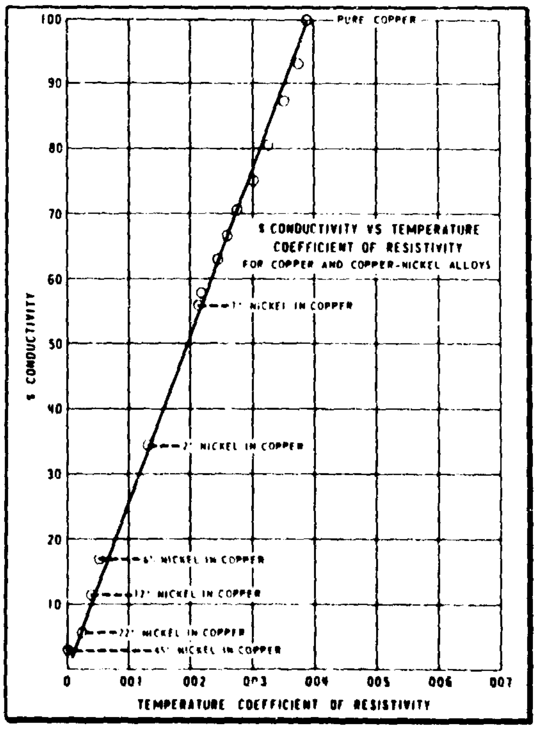

FIGURE 1

Although pure copper shows good conductivity at room temperature, the conductivity falls off rapidly with increase in temperature. The copper with 6% nickel shows very little change in conductivity with increase in temperature; however, the room temperature conductivity is very poor. In selecting a core material, a compromise has to be made somewhere between these extremes. In other words, you can not have both good room temperature conductivity and and have this conductivity remain relatively constant as temperature increases; however, note in figure 2 that at elevated temperatures the alloys have relatively good conductivity as compared to copper.

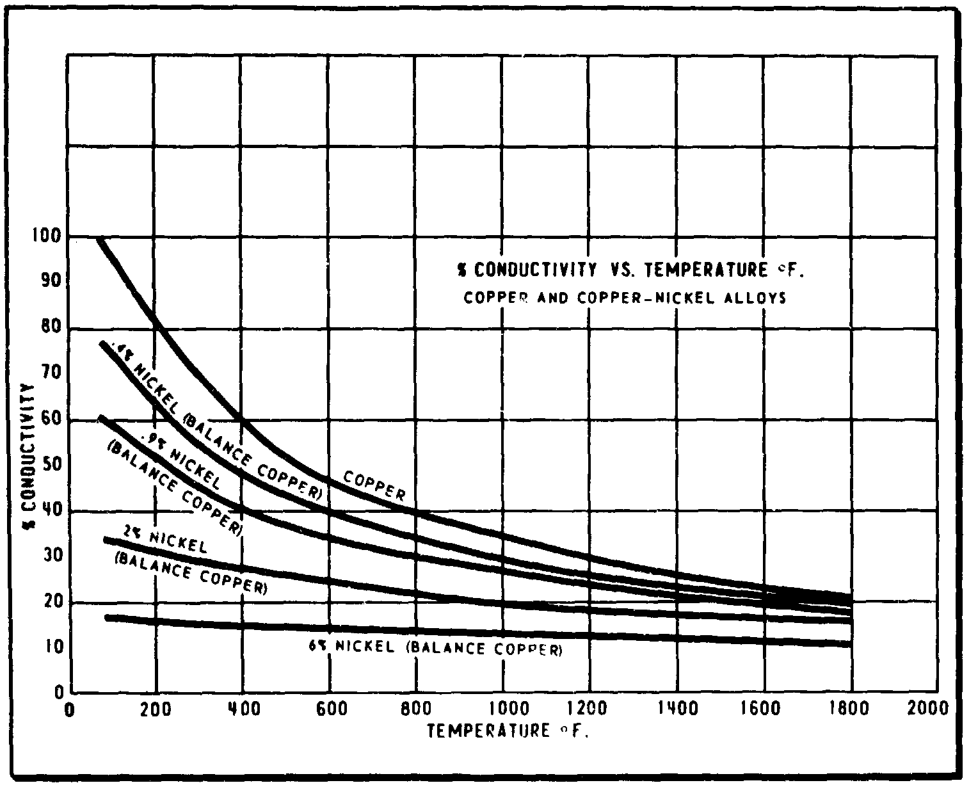

FIGURE 2

In selecting the jacket material for protection at elevated temperatures, resistance to oxidation is the most important single factor. Metals that form an oxide which has a high melting point and low electrical conductivity result in the most dense, adherent, and protective scales. Chromium is the most important component of heat resistant alloys and the proportion of chromium required to result in a low scaling rate increases with increasing temperature. Additions of nickel result in only minor improvements in oxidation resistance in comparison with the effect of additions of chromium. As the chromium content of the alloys increases, the influence of nickel is less pronounced. Aluminum and

silicon increase the oxidation resistance but result in alloys difficult to work. The range of stability of metals in oxidizing atmospheres is influenced by factors such as heating cycles, rate of heating, atmosphere composition, pressure, and rate of flow. These factors may affect the structure, composition, and adherence of the oxide scale; therefore, any comparative listing of alloys with respect to scaling resistance must be for a given condition. Since the "cladding" material has a high resistance in comparison to the core material, it contributes very little to the overall conductivity. This protective sheath, however, contributes significantly to the tensile strength of the conductor at both room temperature and elevated temperature. The overall conductor strength can be controlled by the alloy used and the thickness of coating. Obtaining added strength by increasing the thickness, however, is done at the sacrifice of conductivity. Where a minimum conductivity is specified at some elevated temperature, the maximum percentage of protective coating which can be employed may be calculated by the following formula:

$$F_o = \frac{1 - P_1 / P_t}{1 - P_1 / P_o}$$

Where:

F_o = Maximum fraction of protective coating (fraction of total cross sectional area).

P_t = Maximum desired resistivity of composite wire at given temperature.

P_o = Resistivity of protective coating at given temperature.

P_1 = Resistivity of core material at given temperature.

The above relationship is calculated from ohms law of parallel conductors.

In applications where strength and reliability can be sacrificed, improved stability of conductivity and conductivity itself, over long periods of operation, can be attained. This is illustrated in figure 3 where resistivity, for various percentages of nickel on copper, is shown for time intervals 0 to 500 hours operation. Note that the thinner the coating, the more stable the resistivity with time at temperature and the better the conductivity throughout life. This situation occurs from diffusion of the cladding material into the copper during operation. This diffusion takes place to the same depth in the copper regardless of the coating thickness. Therefore, for heavy coatings the percent of total copper affected is greater than for light coatings, resulting in a greater change in resistivity.

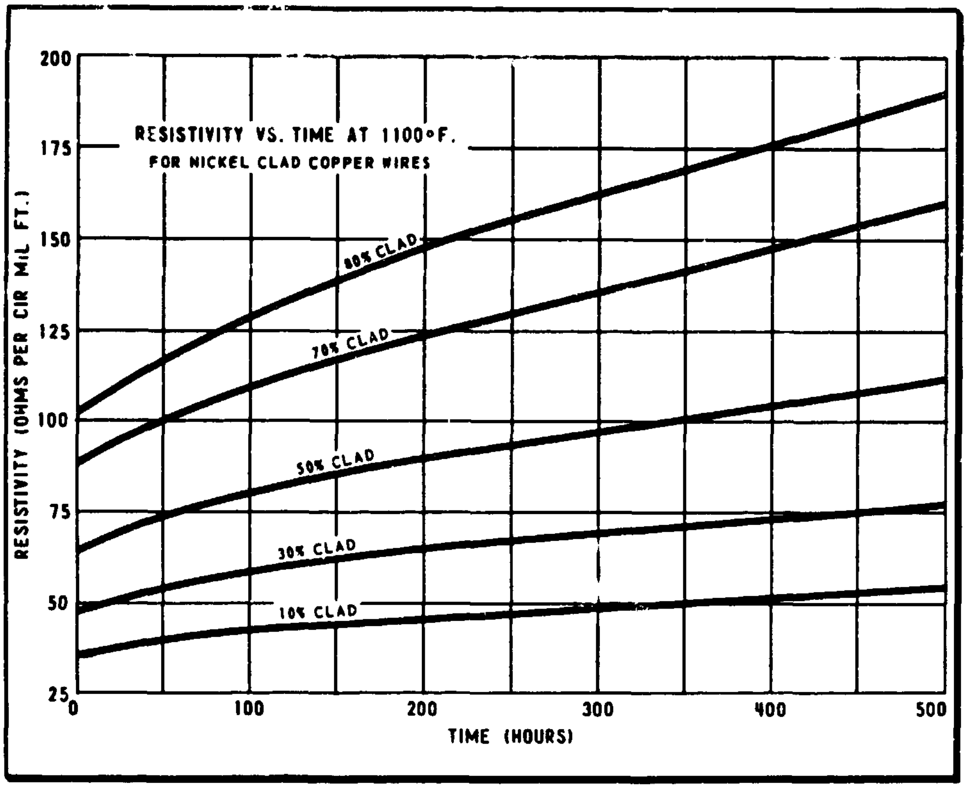

FIGURE 3

If a low temperature coefficient of resistivity is desired, care must be exercised when pure metals with relatively low resistivity and high temperature coefficient are employed as the protective coating. Figure 4 shows the effect of the thickness of clad on temperature coefficient for several nickel clad copper-nickel alloys. On the core alloys with the lowest temperature coefficient, i.e., copper with 6% nickel, this graph shows how the composite temperature coefficient increases at a more rapid rate with increase in cladding percentage. This is logical because, as the percent of material with a high temperature coefficient increases and the percent of material with a low temperature coefficient decreases, the higher temperature coefficient material contributes more to the change in resistivity with temperature of the composite wire. The larger the ratio of temperature coefficient between the coating and the clad, the more pronounced this effect becomes. When this ratio becomes less than unity, the composite temperature coefficient will decrease with increase in cladding percentage. For this reason, protective coating alloys of high resistivity and low temperature coefficient can result in a lower temperature coefficient on the composite wire.

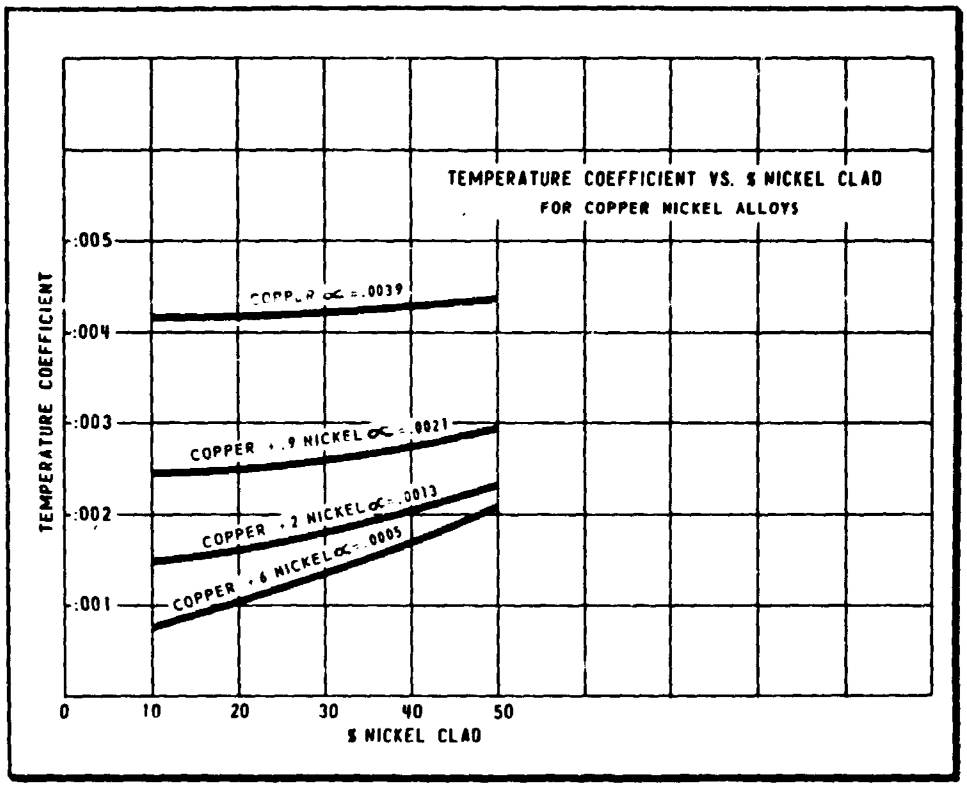

FIGURE 4

Several composite wires are presently available for operation at "ultra high" temperatures. Depending on the final properties, others could be developed to meet specific requirements. Three such composite wires available today are: Kulgrid, Oxalloy, and Inconel Clad Copper. Kulgrid is a 28% nickel clad OFHC copper wire and Oxalloy is a 28% stainless steel clad OFHC copper wire. Figure 5 shows 500 hour life tests on each of the above three conductors. At the specified temperature, each shows little change in conductivity throughout the 500 hour interval. All tests were made on 36 gauge single ended wires. These conductors can be operated at higher temperatures than shown in figure 5. For instance, figure 6 shows 500 hour life test results for the three wires at 1100° F. While both Inconel Clad Copper and Oxalloy are relatively stable at this temperature, the Kulgrid loses conductivity at a rapid rate. Kulgrid, however, has been operated up to 1200° F. Oxalloy, the most stable of the three, can be operated up to 1300° F.

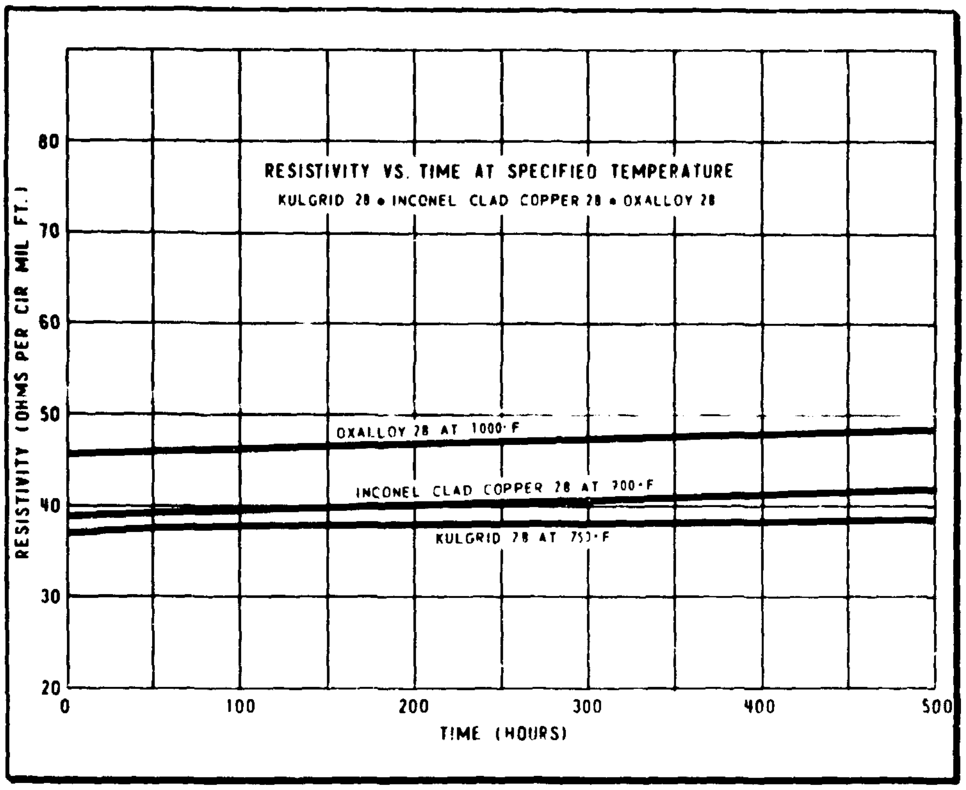

FIGURE 5

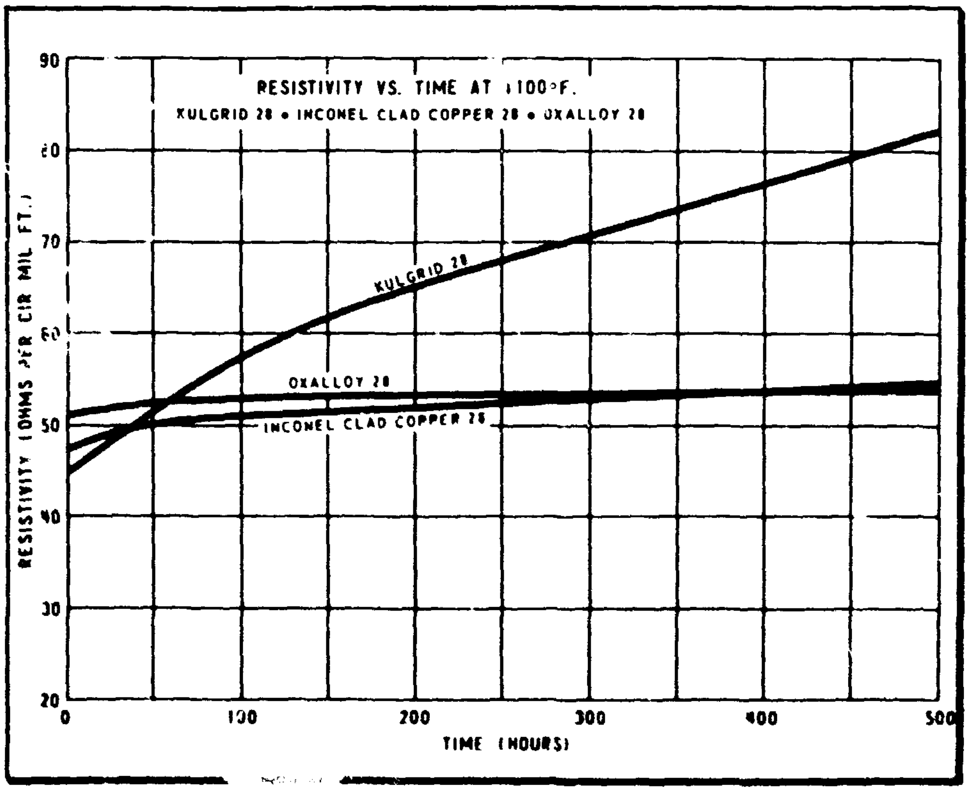

FIGURE 6

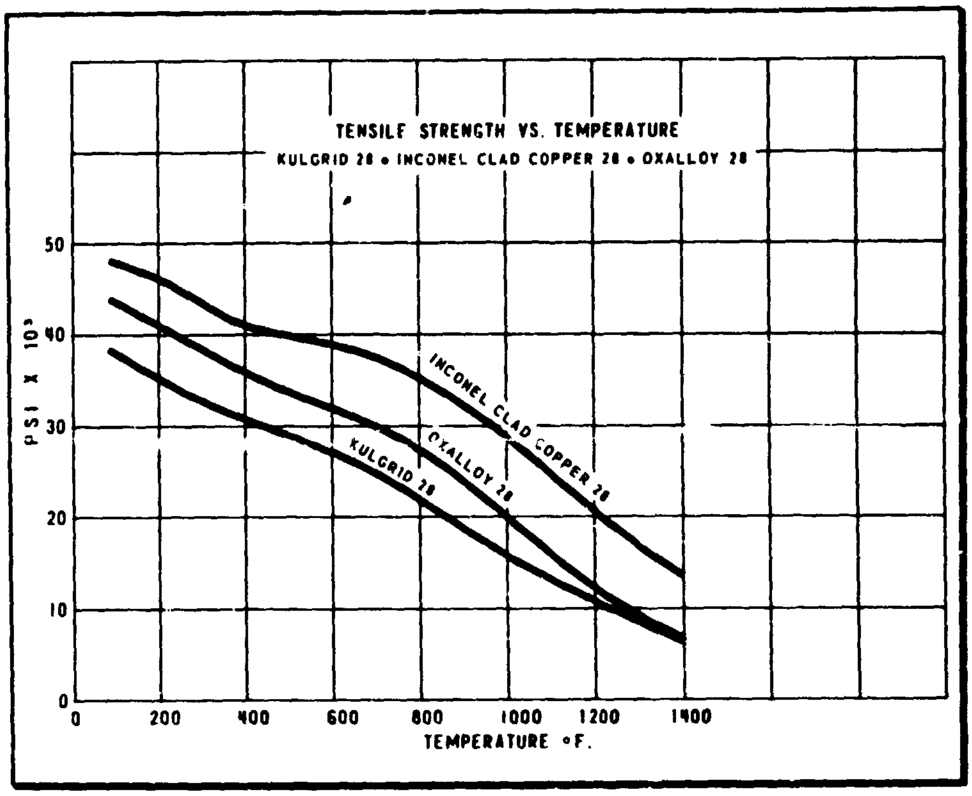

FIGURE 7

Figure 7 shows the tensile strength at various temperatures up to 1400° F. Kulgrid, at its operating temperature of 750° F, has a tensile strength of 23,500 psi.; Inconel Clad Copper, at 900° F, has a tensile strength of 32,000 psi.; and Oxalloy, at 1000° F, has a tensile strength of 20,000 psi.

In summary, several factors have to be considered when specific properties are desired in a high temperature wire. These include:

1. Conductivity
2. Temperature coefficient of resistivity
3. Oxidation resistance and resistance to other corrosive media
4. Tensile strength at room and elevated temperatures
5. Thickness of protective coating

Many times a specific property can only be attained at the sacrifice of one or more other properties. Therefore, to design a composite, the desirable characteristics must be clearly spelled out, and the best possible compromise between all the factors has to be determined—first, by calculation, and secondly, by long and tedious testing. In general, a compromise can usually be made and the optimum conductor developed.